PROGRAMS FOR PROCESSING THE DATA OF LONG TERM ELECTROCARDIOGRAPHIC RECORDS IN ORDER TO EVALUATE HEART RATE VARIABILITY.

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Reduced heart rate variability (HRV) has been reported as a predictor of mortality in recent myocardial infarction patients. HRV has usually been expressed as the standard deviation of the computer recognised sequence of RR intervals based on long term ECG recordings. However, recording noise and variability requires 'filtering' of the data and visual checking and editing which makes this method not widely acceptable.

Based on theoretical and clinical work, a new package of programs has been developed which permit the analysis of Holter tapes and numerical assessment of HRV which is not affected by low level noise and misrecognition artefact. The HRV is approximated as the baseline width of the main peak of the frequency distribution curve of durations of RR intervals which is computed by means of its minimum square difference triangular interpolation. Another part of the package uses a complex modification of this formula to evaluate the spectral components of HRV which can be restricted by different wavelength limits from 1 second (1 Hz) up to 24 hours (0.000001 Hz). Based on a similar principle, the estimated spectral components are also not affected by low level noise and artefact in the original recordings. The programs of the package have been written in *Turbo Pascal 5.0* and their source texts represent approximately 3000 lines of the code. The input to the package consists of the digitised Holter tapes, the output is provided either in the form of numerical tables or as standard ASCII files which are suitable for a subsequent statistical analysis.

The package has been used for the analysis of more than 300 Holter tapes collected during 3 years in patients who survived after acute myocardial infarction. The retrospective clinical study showed that the results provided by the package correlated strongly with the mortality of patients during their follow up. This proved that the package offers automated evaluation of HRV which is of the same prognostic value as the results obtained from the operator dependent, manually filtered and visually checked analysis of Holter tapes.

SYSTEM FOR THE DIAGNOSIS OF PACED ELECTROCARDIOGRAMS

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An ECG not associated with a pacemaker marker channel, is often the only information for establishing the heart-pacemaker interaction (HPI), and for diagnosis of pacemaker failure. The possible explanation and interpretation of paced ECGs may be difficult because of pacemaker specification and idiosyncrasy, and because of hidden interactions between the pacemaker and its environment. A computer system providing an analysis of the HPI based on ECG data has been developed for IBM PC AT compatible computers. The system employs a complex algorithm which enables all possible combinations of HPI events to be considered and evaluated in order to establish whether they correspond to the pacemaker's mode and programmed characteristics. The program of the diagnostics system is written in *Turbo Pascal* (more than 11000 lines of source text) and its time and memory demands depend on the complexity of the case for analysis; 450 kbyte and less than 10 seconds of CPU time (not including the print of results) were sufficient for all cases. The system has been tested with several models of clinically realistic pulse generators and accepts descriptions of various devices including the most recent rate-responsive modes. The system inputs the description of the pacemaker mode and of its programming, and the description of the analysed ECG in the form of timing of *definite* and *possible* sensing events and of *definite* and *possible* generator pulses. The computer then establishes whether the device operates correctly within its permitted error and prints a simplified pattern of the given ECG trace accompanied by a simulated marker channel explaining the diagnosed case. Should the evaluated case permit more possible explanations, all of them are comprehended by the system and their traces can be printed. The output of the system contains simplified patterns of the given ECG accompanied by simulated marker channels which trace the possible HPI. The system permits the distinction between atrial and ventricular pacing spikes, paced and natural extrasystolic depolarisations. It has been successfully used to evaluate the cases of clinical ECG traces exhibiting: (1) pacemaker undersensing, (2) fusions of pacing pulses with natural depolarisations, (3) accuracy of paced rhythm, (4) diagnosis of ventricular depolarisations caused by atrial pacing.

NONLINEAR DYNAMIC ANALYSIS OF ELECTROCARDIOGRAPHIC SIGNALS

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Recent advances in the mathematics of nonlinear dynamics have led to its application in biology and cardiology. A series of graphical programs have been written to aid the understanding of chaotic signals and processes, and to analyze biological signals. All programs were written in Pascal for use on IBM personal computers.

The first program generates standard signals. Sine, square, triangular, sawtooth, quasiperiodic and modulated (amplitude and frequency) sine waves of any desired frequency, digitization rate and amplitude can be produced in files up to 10,190 points in length. Linear or Gaussian noise of any amplitude can be added to the signals.

Chaotic signals are generated by using a fourth-order Runge-Kutta algorithm for the solution of systems of differential equations (e.g., Lorenz, Rossler, Duffing, Silnikov, Van der Pol). Length of data files generated is limited only by the size of the hard disk. Programs for production of chaotic maps (logistic, Henon) and for the bifurcation diagram of the logistic map are also included. Random signals are constructed by filtering a pseudorandom number series, or any other random time-series.

Standard and electrocardiographic signals (digitized at 1000 kHz) are analyzed by phase plane plots, return maps and spectral analysis. Three types of phase plane plots are constructed (amplitude vs first derivative, amplitude vs second derivative, and first vs second derivative), but the program can be modified to generate any desired combination of amplitude or derivative. Return maps are constructed by choosing a lag of interest, and maps with that lag and three multiples of that lag are displayed.

Spectral analysis by fast Fourier transformation (FFT) is performed at a resolution of 8,192 points on data files of any length (by truncation or zero padding). The spectrum is displayed as either the raw FFT, power spectrum, or log FFT. Hard copy of all the graphs can be obtained by a screen dump.

A SYSTEM FOR ON-LINE INTRAOPERATIVE ASSESSMENT OF REGIONAL MYOCARDIAL PERFUSION IN HUMANS.

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We have developed an on-line image analysis system to aid in the intraoperative assessment of regional myocardial perfusion during myocardial contrast two-dimensional echocardiography. This system consists of a 80386 microprocessor (System 310, Dell Computer Corp.) with a clock speed of 20 MHz, 640 kilobytes of memory, a 40 megabyte hard disk, and a color monitor. Analog to digital conversion of images is performed using an internal frame grabber (PC Vision +, Imaging Technology) which permits image capture (512 x 512 x 8) at a frame rate of 30/sec. Videointensity analysis is performed in each frame in up to 6 observer placed regions of interest. Videointensity results are stored in memory, and at the end of the injection sequence are displayed as time-intensity plots. Background (average videointensity in the region of interest prior to appearance of contrast), is automatically subtracted from each data point on the plot and the exponential function: $a(e^{-\alpha t}-e^{-\beta t})$ is applied to the plot using a commercially available data analysis system (RS/1, Bolt, Beranek and Newman). Parameters of the time-intensity curve such as the area under the curve, initial slope of the curve, curve width, and the washout of contrast are automatically calculated. The data (curves and parameters) prior to and following bypass operation are displayed side by side for evaluation.

In conclusion, we have developed a system for the on-line analysis of myocardial perfusion using myocardial contrast two-dimensional echocardiography. This system can aid in the intraoperative assessment of regional myocardial perfusion prior to and following bypass graft placement.